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Improved Reconstruction of DPCM-Coded Pictures

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A new scheme for the reconstruction of DPCM*-coded signals is presented. In this scheme, instead of assigning one representative level to the prediction error whenever it is in a range determined by the decision levels of a* DPCM *quantizer, surrounding local picture structure is used to improve the reconstruction. No extra transmission is required. Mean-absolute-reconstruction error is decreased by over 20 percent, and the picture quality is significantly improved in flat, as well as high, detailed areas of still pictures and sequences of pictures containing motion.*

I. INTRODUCTION

In most picture communication systems that employ any type of quantized encoding, samples are sequentially encoded, transmitted by the channel and reproduced at the receiver. Pulse-Code Modulation (PCM) systems assign one of the many quantization levels to the amplitude of each sample, whereas differential pulse-code modulation (DPCM) systems assign a quantizer level to the prediction error of each sample.[1] Thus, in PCM systems, no use of the correlation between the adjacent picture samples is made either at the transmitter for coding or at the receivers for display. In DPCM, the "previously" coded sample values are used for computing the prediction of the "present" sample at the transmitter, and thus correlation of the present element with the previous pels is utilized. However, no use of the "future" samples is made at the transmitter or at the receiver.

In this paper, we present techniques for coding and display that use correlation between the present sample, and its past and future neighbors. At the transmitter, this improves the prediction; and at the receiver, this results in a more accurate reproduction of the intensity for display. The technique can be used at the receiver, or at the

transmitter, or both. For example, its use only at the receiver amounts to postprocessing of the coded data received from a standard DPCM transmitter. Each sample that is DPCM coded with a coarse quantizer is known at the receiver to be in a range that is determined by the prediction and the coarseness of the quantizer. Knowing the ranges of surrounding neighboring samples, a new representative value can be assigned to each sample.

We describe a technique for such an assignment and give results of computer simulations on still pictures, as well as a sequence of frames containing motion. Simulations show that in areas containing high-spatial correlation, improvement using our technique is the greatest. In DPCM systems, this corresponds to samples whose prediction error occupies the "inner" (close to zero) levels of the quantizer. Coarseness of the quantizer in these areas shows as granular noise, which is reduced by our technique. However, this reduction occurs without the blurring of high-detailed areas associated, for example, with low-pass filtering. Comparison of the quality of the pictures shows that edge busyness and slope overload are also reduced, but this improvement is not reflected proportionately in the mean-square-reconstruction error.

II. ALGORITHM

In the basic DPCM system, a prediction of the present sample (e.g., sample X in Fig. 1) is made from the previously encoded information that is already transmitted to the receiver. Thus, in Fig. 1, the intensity of pel X can be predicted by $\hat{A}$, or $(\hat{A} + \hat{D})/2$, where $\hat{A}$ and $\hat{D}$ are the reconstructed values of samples A and D. The error resulting from the subtraction of the prediction from the actual value of pel X is quantized into a set of discrete amplitude levels. Thus, a quantized form of $(X - \hat{A})$ may be sent if the so-called previous element predictor is used. The quantizer levels are represented as binary words of either fixed or variable length and sent to the channel for transmission. If the prediction error, e, falls within the two consecutive decision levels e_1, and e_2, then the receiver knows the intensity of the sample to be within the

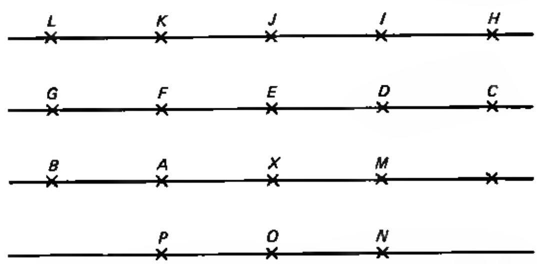

Fig. 1—Pel configuration for intraframe processing.

range $[(P + e_1), (P + e_2)]$, where P is the prediction value. Traditionally, a representative level e_r, is chosen to represent e in the range $[e_1 e_2]$ and the reconstruction at the receiver is taken to be $(P + e_r)$. Such a reconstruction is based on the representative level e_r, which is chosen to minimize certain average error.[2,3,4] However, pictures are highly nonhomogeneous and nonstationary; therefore, benefit can be derived by choosing a representative level based on the local characteristics of the picture. However, if no additional information is transmitted to the receiver, the local characteristics have to be estimated based on the quantized information. The problem then is to estimate the intensity of pel X,

(*i*) knowing that it is in the range $[P + e_1, P + e_2]$ and

(*ii*) knowing the ranges of the surrounding correlated elements, such as A, M, F, E, D, P, O, N, etc.

Since elements A, M, $\cdots$, N are correlated with element X, their range information should give a better estimate of the pel intensity at X. Since an accurate model for the picture signal does not yet exist, we could not apply estimation theory. Instead, we tried several intuitively reasonable techniques, and the following appears to be the best for the set of pictures used. The following steps are used in the reconstruction algorithm.

1. Use a set of predetermined surrounding elements, e.g., A, M, F, E, D, P, O, and N.

2. Determine the normal (i.e., using a standard DPCM receiver) reconstructed value for X, and the surrounding elements.

3. Knowing p, the prediction of X, determine the range for X, i.e., $[p + e_1, p + e_2]$, in addition to its normal reconstructed value $p + e_r$.

4. Let n and m be the number of surrounding elements having normal reconstructed value less than and more than $(p + e_r)$, respectively. Then, the new reconstruction for element X is*

$$\begin{aligned} \hat{X} &= \frac{n(p + e_1) + m(p + e_r)}{(n + m)}, && \text{if} \quad n > m \\ &= \frac{n(p + e_r) + m(p + e_2)}{(n + m)} && \text{if} \quad n < m \\ &= p + (e_1 + e_2)/2 && \text{if} \quad n = m. \end{aligned}$$

Thus, the new reconstruction is a weighted sum of the endpoints of the range, where the weights are determined by the surrounding elements. Since the new reconstruction maintains the value of the

* If n is close to m and changes slightly from sample to sample, the above reconstruction may show jumps from sample to sample. This provides a dithering effect that appears to improve the picture quality.

element X within the range $[P + e_1, P + e_2]$, the filtering action of the weighted averaging process does not blur the edges significantly. It is possible to choose tbe "surrounding" elements that have characteristics similar to the element X, so that the averaging does not produce any noticeable artifact.

The algorithm described above is primarily for postprocessing at the receiver for better reconstruction. It is also possible to use the algorithm for preprocessing at the transmitter. In traditional DPCM, reconstructed values are used for prediction. Therefore, it is possible to use only the previously transmitted pels to improve the reconstruction and then use this better-reconstructed value for prediction. The constraint that only previously transmitted values can be used for improved reconstruction limits the improvement when intraframe predictors are used. As an example, if previous element A is used for prediction of X, tben better reconstruction of A can be performed by using only surrounding transmitted neighboring pels, such as B, E, F, A, etc. Since other neighbors, such as elements X, P, and O cannot be used, smaller improvement in reconstruction is obtained. However, in the case of frame-to-frame coding, substantial improvement is possible. For example, in Fig. 2, previous frame element, $\bar{X}$, can be reconstructed using all the elements in the 3×3 neighborhood, since they would be available at the receiver at the time of coding present element X.

III. SIMULATION RESULTS

We performed computer simulations to evaluate the improvements using our reconstruction techniques. The still frames used were 256×256 pel arrays with each pel quantized to 8 bits (levels 0 to 255). These are shown in Figs. 3 and 4. The sequence of frames containing motion, consists of 64 frames called "JUDY." Four frames from this sequence are shown in Fig. 4 of Ref. 5. For simulation with still frames, two predictors, A (previous element), $(A + D)/2$ (planar, two dimensional) were used. Three symmetric, even-level quantizers were used. Their positive decision levels are given below:

$$Q_1 : 0, 10, 255, \quad 4 \text{ levels}.$$

$$Q_2 : 0, 3, 9, 29, 255, 8 \text{ levels}.$$

$$Q_3 : 0, 10, 25, 43, 255, 8 \text{ levels}.$$

The mean-absolute-reconstruction error (i.e., the magnitude of the difference between the original and the reconstructed picture) was calculated for botb pictures with standard DPCM and the improved DPCM described in tbe previous section. As mentioned before, since the intraframe coding does not allow significant improvements at the transmitter using our techniques, only postprocessing at the receiver

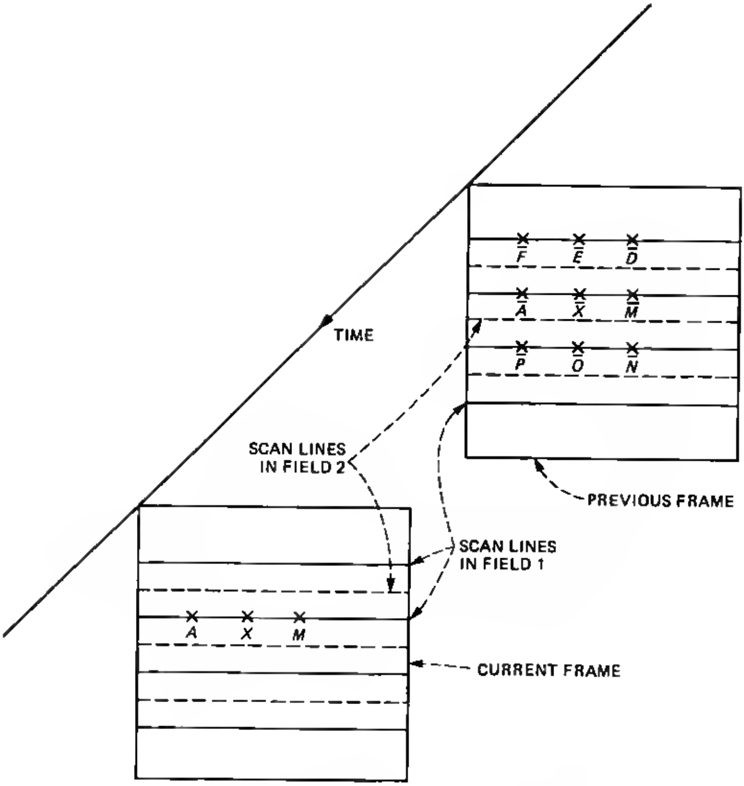

Fig. 2—Pel configuration for interframe processing.

was performed. Three cases were considered, depending on the number of neighbors used. Case 1 used three neighbors, A, X, and M; Case 2 used five neighbors, A, X, M, E, and O; and Case 3 used nine neighbors, A, X, M, F, E, D, P, O, and N. Tables I and II show the mean-absolute-reconstruction error for various cases. We note that a larger number of neighbors improves the performance of our postprocessing techniques. Large improvements in mean-absolute error are obtained for quantizers that have coarse inner levels. Thus, when quantizers Q_1 and Q_3 are used, we get about 20 percent improvement over the standard DPCM. Although the mean absolute error does not show improvement with quantizer Q_2, the quality of the picture is improved considerably because of improved reconstruction of the low-contrast areas, as well as edges.

Quantizers for intraframe predictive coders usually contain fine inner levels to reduce the visible granular noise in flat areas. If only a small number of levels can be used, then one has to trade off granular noise for other distortions such as edge busyness. It may be possible

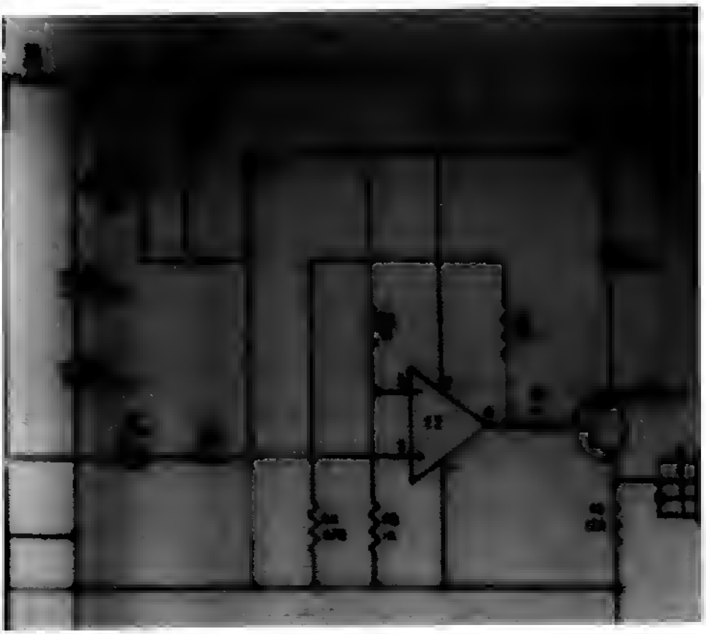

Fig. 3—Circuit diagram used for simulation.

Fig. 4—Checkered girl used for simulation.

with our technique to use a quantizer with coarse inner levels so that better edge reproduction is possible, since granular noise would be mitigated to a large extent.

Simulations of our scheme for a sequence of frames involved an improved DPCM transmitter, as well as receiver. Thus, referring to Fig. 2, three types of schemes were simulated. In the first, conditional replenishment with previous frame predictor (i.e., $\bar{X}$ for prediction of X) and a moving area threshold of 2 (out of 255) was simulated. This

Table I—Comparison of mean-absolute error for circuit diagram

		Number of Neighbors = 3		Number of Neighbors = 5		Number of Neighbors = 9	
		Predictor Used					
		A	$\frac{A+D}{2}$	A	$\frac{A+D}{2}$	A	$\frac{A+D}{2}$
Quantizer used: Q_1	Standard DPCM	5.77	4.81	5.77	4.81	5.77	4.81
	Improved DPCM	5.84	4.92	5.07	4.08	4.87	3.94
Quantizer used: Q_2	Standard DPCM	3.13	2.31	3.13	2.31	3.13	2.31
	Improved DPCM	3.18	2.72	3.07	2.45	3.01	2.40
Quantizer used: Q_3	Standard DPCM	2.92	3.09	2.92	3.09	2.92	3.09
	Improved DPCM	2.95	3.01	2.35	2.20	2.07	2.08

Table II—Comparison of mean-absolute error for checkered girl

		Number of Neighbors = 3		Number of Neighbors = 5		Number of Neighbors = 9	
		Predictor Used					
		A	$\frac{A+D}{2}$	A	$\frac{A+D}{2}$	A	$\frac{A+D}{2}$
Quantizer used: Q_1	Standard DPCM	5.73	3.74	5.73	3.74	5.73	3.74
	Improved DPCM	5.72	3.78	5.21	3.17	5.07	3.13
Quantizer used: Q_2	Standard DPCM	2.96	1.71	2.96	1.71	2.96	1.71
	Improved DPCM	3.04	1.98	2.95	1.79	2.94	1.80
Quantizer used: Q_3	Standard DPCM	2.96	2.79	2.96	2.79	2.96	2.79
	Improved DPCM	3.24	2.80	2.96	2.20	2.44	2.20

was used for comparison. The second scheme was identical to the first, except that the reconstruction of X was done by using the 3×3 neighborhood only when X was a moving area pel. If X is not a moving area pel, then it is reconstructed by using its previous frame value. Thus, only postprocessing at the receiver is used. The third scheme used an improved reconstruction value from the previous frame also for prediction. All three schemes used quantizer Q_3. The results are shown in Figs. 5, 6, and 7. Figure 5 shows the mean-absolute-reconstruction error averaged over all the pels as a function of the frame number. It is easy to see that there is about 20 percent reduction in mean-absolute error because of the improved reconstruction (scheme 2). Also, the improved prediction and reconstruction (i.e., scheme 3) reduces the error further by about 10 percent. Figure 6 shows the improvement when restricted to moving area pels. Since the number of moving area pels differs for the three schemes, total reconstruction error is shown. Considerable improvement is now seen by postprocessing alone and pre- and postprocessing. The total prediction error for all the moving area pels for schemes 1 and 3 are plotted in Fig. 7. Thus, instead of using $\tilde{X}$ for prediction as in scheme 1, if we improved the

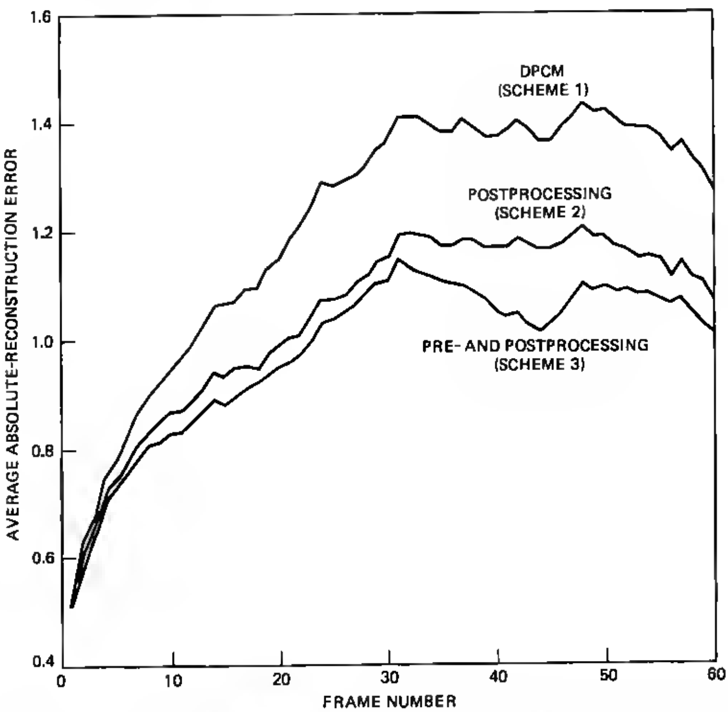

Fig. 5—A plot of the mean-absolute-reconstruction error as a function of the frame number.

predictor using the 3 × 3 surrounding elements around $\bar{X}$, the prediction is improved by over 15 to 20 percent. However, much of this improvement is apparently included in only postprocessing with no change in predictor (scheme 2). The pictures produced by the three schemes were viewed in informal sessions. It was concluded that the "dirty window" effect in moving areas associated with coarse quantization (scheme 1) was removed to a large extent by improved postprocessing (scheme 2). In many cases, the blur in areas of high-contrast edge motion, resulting from a quantizer with insufficient dynamic

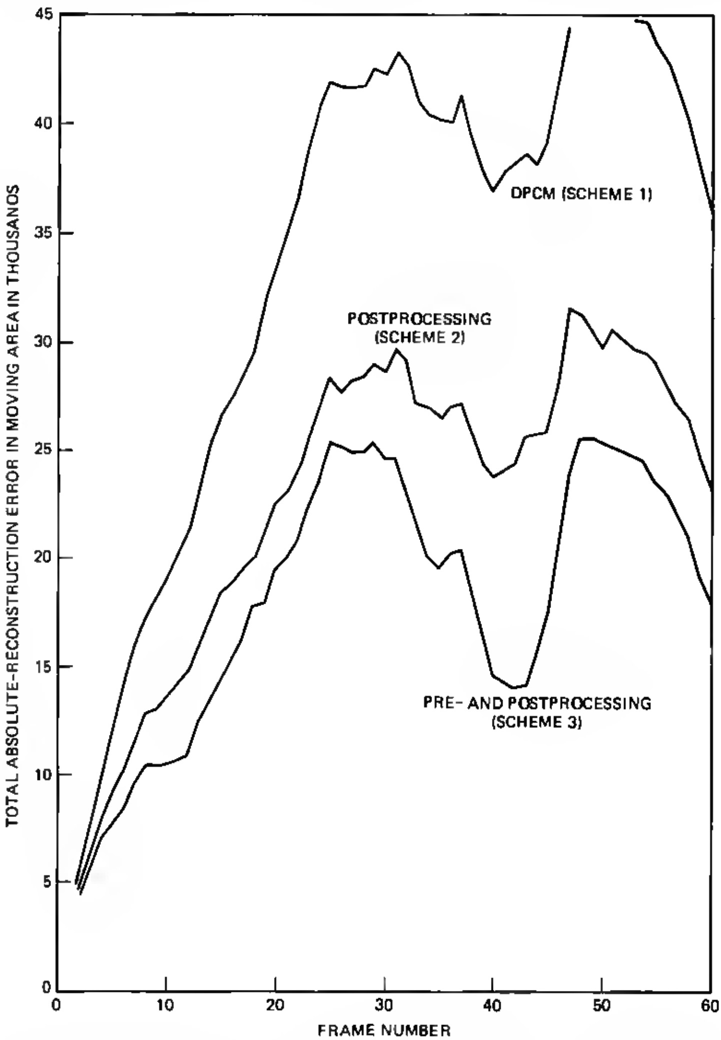

Fig. 6—A plot of the total error in the moving area versus the frame number.

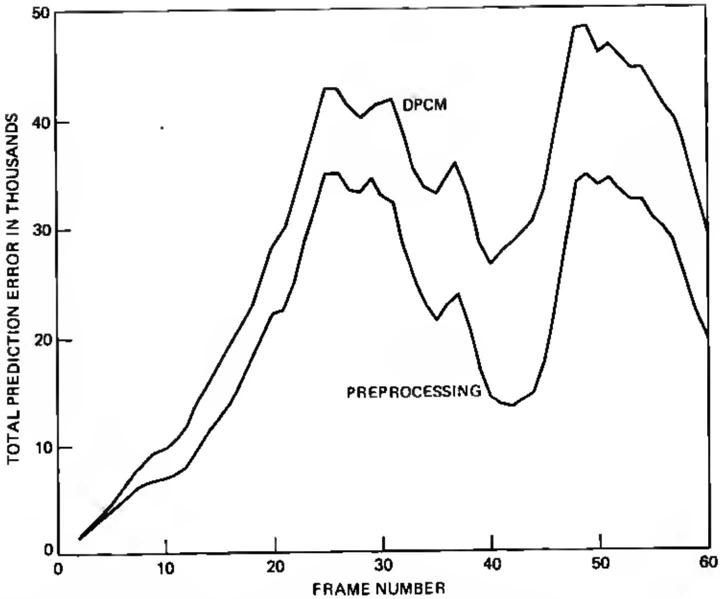

Fig. 7—A plot of the total absolute-prediction error as a function of the frame number.

range, was also reduced. Although the results are not shown when quantizer Q_2 was used, we found that there was improvement in absolute-reconstruction error, and the picture quality showed significant improvements.

IV. SUMMARY AND CONCLUSIONS

We have presented a new method for reconstruction of DPCM-coded samples. Instead of using one representative level whenever the prediction error is within a range, we use local properties of the picture signal to derive an improved reconstruction. No extra transmission is required. Reconstruction error is decreased by over 20 percent, and picture quality is improved significantly. It is possible to use quantizers that have coarse inner levels and to use our techniques to reduce the visible granular noise. Therefore, quantizers with fewer levels can be used. Improvement is obtained for coding of still frames, as well as sequence of frames containing motion.

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